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How do high school science textbooks in Korea, Japan, and the U.S. explain bioaccumulation-related concepts?

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ABSTRACT: Although bioaccumulation-related concepts are important scientific knowledge, a study on whether high school textbooks include appropriate explanations has not been conducted. The present study investigated science and biology textbooks from Korea, Japan, and the U.S., focusing on how bioaccumulation-related concepts were defined, what types of bioaccumulative substances were discussed, and the properties of these substances. The textbooks of these countries tended to focus on biomagnification. While the textbooks from Japan and the U.S. present synthetic organic compounds as examples of bioaccumulative substances, metallic substances were used as examples in all Korean textbooks. However, the discussion about the properties of bioaccumulative substances was brief in the textbooks. Moreover, the bioaccumulative properties of metals and organic compounds were not distinguished. The limited explanations in the textbooks might cause students to have misconceptions about the processes of bioaccumulation and bioaccumulative substances, and negative perceptions toward essential trace metals.

KEY WORDS: bioaccumulation, biomagnification, bioconcentration, science textbook, high school

INTRODUCTION

Today humankind lives in the Anthropocene Era when changes due to human activities like global warming are having a huge impact on global ecosystems (Crutzen, 2002). In addition, modern humans have been releasing many kinds of synthetic organic compounds and toxic metals into various ecosystems, resulting in worldwide effects on the Earth's biosphere (Dachs & Mejanelle, 2010). Bioaccumulation is an important scientific concept in scientific literacy because it is the major principle for understanding and predicting the movement of xenobiotic pollutants in an ecosystem (Clements & Newman, 2002; Zakrzewski, 2002). Essentially, bioaccumulation refers to the accumulation of external substances in organisms without distinction of the inflow path (Arnot & Gobas, 2006). It is also an applied concept based on the food web and trophic transfer,

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and a core principle in ecotoxicology, a fusion of population ecology and toxicology (Clements & Rohr, 2009).

Knowledge about bioaccumulation is also important for the public with respect to a number of practical issues. People are always exposed to the threat of synthetic chemicals in the air, water, and soil. Thus, in modern times, we have an increased risk of environmental hormones that lead to endocrine disorders (Rhind, 2009). Also, the danger from bioaccumulation of toxic substances expands a specific species-level risk to the ecosystem level through food chains (Rohr *et al*., 2006). For example, a specific bioaccumulative pollutant can be found in polar animals without direct exposure to it (Blais *et al*., 2005). Because regional problems can become global problems, bioaccumulation needs to be treated as a global problem like climate change and biodiversity loss (Dachs & Méjanelle, 2010).

From an education perspective, bioaccumulation-related concepts are also important as a part of scientific literacy. Today humankind is affecting all ecosystems more than even before (Crutzen, 2002). Thus, in order to understand interactions between humans and environments on the ecosystem level which are caused by the inflow of xenobiotic substances into the ecosystem, bioaccumulation-related concepts are necessary knowledge and good materials for STS education. In addition, bioaccumulation-related concepts can be utilized for integrated science education, which is a concept that has been raised before (Pring, 1971). Bioaccumulation-related concepts are useful as they require chemical knowledge about the molecular properties of substances, ecological knowledge about food chains, and physiological knowledge about organisms' responses to understand the concepts.

Even though bioaccumulation is one of the important scientific principles needed to understand the relationship between humans and the environment at the ecosystem level, there is a lack of research on bioaccumulation-related content in scientific textbooks. According to an unpublished survey by the authors, biology teachers as well as students were found to have misconceptions about bioaccumulation. Their misconceptions were believed to be due to their textbooks and they especially tended to have a misinformed belief about the biomagnification of toxic trace metals. Therefore, the purpose of this study was to examine the bioaccumulation-related contents of science textbooks. Specifically, this study examines textbooks from Korea, Japan, and the U.S. in an effort to identify concepts presented that can give rise to fallacious beliefs or misconceptions. Japanese use some Chinese characters as part of their writing and some of academic terms written in Chinese characters are shared by Korea and Japan. And the bioaccumulation-related terms was developed in the U.S. Thus, the textbooks from the three countries were chosen. In the following sections, a history of the definition of terms

bioaccumulation, biomagnification, and bioconcentration is introduced to provide the reader with an understanding of the differences between these terms, especially with regards to the underlying processes for each one. Following this introduction, findings are compared and a new proposal for teaching bioaccumulation is shared.

History and Definition of the Terms

There are three terms referring to the accumulation of substances in organisms: bioaccumulation, biomagnification, and bioconcentration (Arnot & Gobas, 2006). First, bioaccumulation is an extensively used term meaning the accumulation of external substances in organisms without distinction of the inflow path (Arnot & Gobas, 2006). It is the term which was first used most widely after the discovery of accumulation in organisms (Connell, 1990).

Since an increase in DDT concentration along food chains was found in the 1960s (Woodwell, 1967), people have become concerned about the danger of increased concentrations of residual substances in humans via consumption of animals and plants in the food chain. Since then, a new term, biological magnification, or biomagnification, was introduced to indicate this phenomenon, which is specifically focuses on understanding the process through dietary absorption (Woodwell *et al*., 1967). Thus, biomagnification mainly focuses on the inflow path through food, stressing its importance in bioaccumulation.

However, experiments concerning accumulation in organisms in an aquatic environment did not always show clear evidence of biomagnification (Hamelink *et al*., 1971). This finding suggested that the absorption of pollutants through the skin or respiratory organs might be important factors in bioaccumulation process. Thus the term bioconcentration, which indicates the processes of indirect absorption through dermal and respiratory tissues separate from the indirect absorption by food intake, began to be used (Streit, 1992).

Since then, the field of ecotoxicology has come to define these terms as follows. Bioaccumulation refers to processes where a substance is absorbed in direct or indirect ways, resulting in the concentration in the organism being greater than in the respiratory medium (air or water) (Arnot & Gobas 2006; Gobas & Morrison, 2000). The English term bioaccumulation has been translated to the Korean term 생물축적, written as 生物蓄積 in Chinese characters (Park, 2009; The Korean Association of Biological Sciences, 2005). Biomagnification is a special case of bioaccumulation in which a substance's concentration in an organism exceeds that in the organism's diet due to dietary absorption (Mackay & Fraser, 2000). The English term biomagnification has been translated to the Korean term 생물증폭, written as 生物增幅 in Chinese characters

(Park, 2009; The Korean Association of Biological Sciences, 2005). In contrast, bioconcentration refers to processes by which a substance is absorbed by an organism from the ambient environment only through an organism's respiratory and dermal surfaces and results in the concentration of the chemical in the organism being greater than in the environment (Arnot & Gobas 2006; Gobas & Morrison, 2000). The English term bioconcentration has been translated to the Korean term 생물농축, written as 生物濃縮 in Chinese characters. Therefore, the terms are differentiated by the inflow path of external substances.

Processes of Bioaccumulation

Since bioaccumulation includes bioconcentration by direct absorption and biomagnification by indirect absorption, bioaccumulation is a result of a combination of bioconcentration and food uptake (Gobas & Morrison, 2000; Mackay & Fraser 2000). However, organisms do not just passively accumulate external substances in the body. They also eliminate them through respiration, excretion, transformation by metabolism, growth dilution, and so on (Arnot & Gobas 2006). Therefore, the extent of bioaccumulation is the net result of the competing processes of uptake and elimination. If bioaccumulation happens in an organism, biomagnification would not necessarily happen (Gray, 2002). In some organisms the concentration level of some bioaccumulative substances can be higher than in ambient environment, but not higher than in their prey. However, some predator organisms can have a concentration higher than in their prey. That is, the bioaccumulation level may differ depending on the biological organism, ecosystem, and substances involved (Connell, 1990). Above all, the highest risk is when the concentration of the toxic substance continuously increases along a food chain (Gobas *et al*., 2009).

Properties of Bioaccumulative Organic Chemicals

Chemical structure, molecular weight and shape, chemical stability, and ionization affect the bioaccumulation of organic chemicals (Connell, 1990). Bioaccumulative organic chemicals have the following physicochemical properties. They are usually aliphatic and aromatic compounds, have mostly carbon-carbon and carbon-hydrogen combinations, and show a high proportion of carbon-halogen. In terms of molecular weight, bioaccumulation tends to increase from over 100, peak at about 350, and then decrease until about 600. Concerning molecular shape, the width of the cross-section is less than 9.5 Å, the surface area is 208-460 $Å^2$, and molecular volume is 260-760 $Å^3$. In addition, they are resistant to degradation and stable for several years in the environment, and have very low ionization. Above all, fat-solubility is the most critical

factor for bioaccumulation. We can predict the bioaccumulation extent of a specific substance if we know the fat-solubility (Gobas *et al*., 2009).

Beyond these properties, biological factors such as lipid volume in the body, species-specific metabolism, age, and reproduction cycle, and environmental factors such as chemical properties of water, such as salinity and pH, and temperature can also influence the extent of bioaccumulation (Barron, 1990). These factors influence the absorption and elimination of external substances, which affect the extent of bioaccumulation. In terms of their effect on bioaccumulation, biological features of organisms can be more critical than their trophic position in food webs (van Straalen, 2008). Therefore, it is necessary to consider a variety of factors when assessing the risk of bioaccumulative substances.

Bioaccumulation of Trace Metals

Bioaccumulative metals have different properties from organic chemicals. Metals are deposited as metallic compounds that are combined with organic or inorganic ligands in organisms (Streit, 1992). Thus, metals can be classified into three groups according to their combining power with ligands, thus indicating their bioaccumulation potential. Metals in Class A usually have a high affinity with ligands of oxygen, and Class B show a high affinity with nitrogen and sulfur. Metals in Borderline can form a complex equally with oxygen, nitrogen, and sulfur. The toxicity of the metal depends on the group (Nieboer & Richardson, 1980). For example, mercury in Class B has relatively high toxicity because its ion has a high affinity with ligands of nitrogen and sulfur, which are abundant in biological tissues.

In addition, the location where the toxic metals are stored in cells can crucially determine the potential of food chain transfer (Hopkin, 1990). Metals usually are accumulated in the following five pools in a cell: 1. the cell membrane, 2. metal-rich granules, 3. metallothionein-like protein, 4. heat sensitive protein, and 5. cell organelles (Wang & Rainbow, 2006). Among these pools, the latter three regions (3, 4, and 5) accumulate metals trophically available and thus the accumulated metals are mostly absorbed and assimilated by the predator (Wallace & Luoma, 2003).

If they are stored in the regions easily degraded in the predator's digestive organs, they can be easily absorbed into the body. That is, they are easily transferred to high trophic organisms through a food chain and tend to biomagnify. The distribution in a cell depends on the metal and the species, thus biomagnification differs among metals and food interactions (Hopkin, 1990).

For example, the main way cadmium and lead are stored in a cell are metallothionein protein and insoluble granules, respectively. Lead is in the Borderline group as well as cadmium, but biomagnification of lead rarely

occurs in ecosystems because the insoluble granule does not degrade well and can be easily excreted (Rubio-Franchini *et al*., 2008).

Shortcomings of Knowledge about Bioaccumulation-related Concepts

Knowledge about the bioaccumulation of xenobiotics is part of as scientific literacy, and is necessary for understanding the risk of bioaccumulative substances to humans at the top trophic level. Since the number and variety of new synthetic compounds have increased, the standards for the risk of bioaccumulative substances have been changing (Gobas *et al*., 2009). This is because although some compounds were considered to have no bioaccumulative risks in aquatic ecosystems based on previous knowledge, they could be found to have risks in terrestrial ecosystems. Thus, we need to have accurate knowledge on bioaccumulation in order to make scientific judgments on the risks of new bioaccumulative substances.

However, one problem is that our current understandings of bioaccumulation are superficial. When we say bioaccumulation, we recall only the process in which a substance is increasingly concentrated in higher trophic levels through a food chain. We also have stereotypes about bioaccumulative substances. In particular, most people have a stereotype about the bioaccumulation of heavy metals. For example, most people think all heavy metals including lead are concentrated in organisms at high trophic levels through food chains or, in other words, biomagnified. Thus, most individuals see lead as a primarily biomagnified substance, though this is not the case.

Such misconceptions can be promoted by educational materials in schools. Textbooks often serve as the most important resource for school science teaching, often serving to concretize curriculum and to form the basis of communication between teachers and students (DeLeuil, 1998). A survey by Choi and Kim (1996) found that most students and teachers depend on scientific textbooks in science classes. Further, students anticipate that textbooks will provide them with scientifically fundamental concepts and principles (Sohn & Park, 2002). However, even though new findings are widely shared by specialists, the ideas that are odds with current scientific knowledge often remain included in textbooks (Albuquerque *et al*., 2008). Since science textbooks actually can serve as sources of misconceptions for students (Park & Cho, 1986; Paik & Song, 2002; Albuquerque *et al*., 2008), we must devote more effort to verifying the scientific concepts in science textbooks (Kook, 2003).

Study purpose

Many studies have dealt with misconceptions about global environmental problems like global warming, ozone layer depletion, and acid rain.

Contents on global warming in scientific textbooks were examined and revealed to be a source of misconception (Kook, 2003). As mentioned above, however, though bioaccumulation is one of the most important scientific principles needed to understand the relationship between humans and the environment at the ecosystem level, a lack of research on bioaccumulation-related content in scientific textbooks is apparent. According to an unpublished survey by the authors, biology teachers as well as students were found to have broad misconceptions about bioaccumulation. Those studied believed these misconceptions were could be traced to their textbooks, especially with regard to misinformed beliefs about the biomagnification of toxic trace metals.

The purpose of this study was to examine bioaccumulation-related content in science textbooks from three countries, Korea, Japan, and the U.S. The intent of this comparative analysis of science textbooks was to identify misconceptions in textbooks that might account for related misunderstandings, and to create appropriate alternative materials for teaching bioaccumulation-related concepts.

MATERIALS AND METHODS

The subjects of our study were 9 high school science textbooks from Korea (Table 1), 7 high school biology textbooks from Japan (Table 2), and 2 high school biology textbooks from U.S. (Table 2). The authors chose the Korean high school textbooks that had been used for the period from 2002 to 2010 because the contents of bioaccumulation were excluded in the textbooks since 2011. The textbooks from Japan and U.S., published around the same time, were chosen for the comparison. In particular, the textbooks from Korea and Japan contained the bioaccumulation-related terms written in the same Chinese characters. The U.S. textbooks were expected to give standards for the comparison because the terms related to bioaccumulation have been first used in U.S.

These high school textbooks were examined focusing on the definitions of the bioaccumulation-related terms used, the types of bioaccumulative substances presented, and the properties of bioaccumulative substances discussed. The comparison of the concepts examined in the textbooks with scientifically reasonable knowledge about bioaccumulation-related concepts revealed the shortcomings of the textbooks. A new direction for the textbooks was proposed based on the analysis.

Table 1. Korean high school science textbooks examined

Code	Textbook	Publisher	Year
H-1	High school Science (고등학교 과학)	㈜교학사	2001
H-2	High school Science (고등학교 과학)	㈜금성출판사	2001
H-3	High school Science (고등학교 과학)	대한교과서	2001
H-4	High school Science (고등학교 과학)	㈜ 도 서 출 판 디딤돌	2001
H-5	High school Science (고등학교 과학)	㈜문원각	2001
H-6	High school Science (고등학교 과학)	서울교육정보	2001
H-7	High school Science (고등학교 과학)	㈜지학사	2001
H-8	High school Science (고등학교 과학)	㈜천재교육	2001
H-9	High school Science (고등학교 과학)	홍지 P&M	2001

Table 2. Japanese and American high school textbooks examined

Code	Nation	Textbook	Publisher	Year
J-1	Japan	High school Biology (高等学校 生物II)	数研出版	2003
J-2	Japan	High school Biology (高等学校 生物II)	第一學習社	2003
J-3	Japan	High school Biology (高等学校 生物II)	教育出版	2003
J-4	Japan	High school Biology (高等学校 生物II)	啓林館	2003
J-5	Japan	High school Biology (高等学校 生物II)	実教出版	2003
J-6	Japan	High school Biology (高等学校 生物II)	三省堂	2003
J-7	Japan	High school Biology (高等学校 生物II)	大日本図書	2003
A-1	U.S.	Biology: The Living Science	Prentice-Hall, Inc.	2000
A-2	U.S.	Biology: Principles & Explorations	Holt, Rinehart and Winston	2001

RESULTS AND DISCUSSION

Terms used and their definitions in the high school textbooks

In bioaccumulation-related content, all the science textbooks of Korean high schools used the term "생물농축", defining the term as a phenomenon of the concentration increase of some substances at higher trophic levels through food chains (Table 3). The term "생물농축" corresponds to bioconcentration (Park, 2009; The Korean Association of Biological Sciences, 2005), but its definition in the textbooks included the concentration increase through a food chain. That is, the definition of the term in the textbooks highlighted the food chain and higher trophic level concentration. In fact, the concept as explained in these texts corresponds to biomagnification based on the definition of the term in ecotoxicology (Park, 2009; The Korean Association of Biological Sciences, 2005). Thus, the textbooks seemed to only focus on a food chain transfer in the process of bioaccumulation.

The high school biology textbooks from Japan used the term "生物濃縮" (Table 4). Its Korean pronunciation is "생물농축", the same term used in the Korean textbooks. However, unlike the Korean textbooks, six of the seven Japanese textbooks explained the term as the phenomenon of accumulating substances at a higher concentration in organisms than in the environment. This definition corresponds to bioaccumulation as we have defined it. In addition to this explanation, the Japanese textbooks offered an explanation about biomagnifying phenomena independent of the previous term. The one textbook which is the exception (J-2) defines the term "生物濃縮" as the phenomenon of increasing concentration in living organisms at higher trophic levels through the food chain of the ecosystem.

The two high school biology textbooks from the U.S. used "biological magnification" and defined it as a process in which a substance becomes increasingly concentrated through the trophic levels of the food chain (Table 4). That is, the U.S. textbooks also covered the process of bioaccumulation through dietary absorption.

Clearly, the terms and explanations in these three countries focused exclusively on biomagnification, which is a special case of the phenomenon of bioaccumulation. The textbooks presented a phenomenon-oriented explanation rather than the process-oriented one. Since the appearance of biomagnification depends on variable related to the ecosystem, organism, and substance, the assessment of risk for the toxic and potential bioaccumulated substances needs to distinguish these concepts in terms of ecotoxicology (Environmental Protection Agency,

2011; Gobas et al., 2009). Limited explanations without the distinctions of absorption routes might make students think that biomagnification is all about bioaccumulation, thus overlooking other significant routes, such as the dermal and respiratory organs.

In addition, the textbooks from Korea and Japan applied bioaccumulation-related terms to concepts different from their scientific sense. That is, the textbooks used the term "생물농축" to explain "biomagnification", although this term means "bioconcentration" in the Korean science community. This indicates that the science textbook authors also have unclear concepts and incorrect knowledge about bioaccumulation. When the meaning of a scientific term is different between textbooks and scientific societies, the confusion in the usage of the term can lead to a misconception (Bahar *et al*., 2008).

There was also considerable imprecision in the terminology used in Japan. In the Japanese textbooks, "生物濃縮", which is read as "생물농축" in Korean, was used for two different concepts. In the Japanese dictionary, "bioaccumulation" is translated as "生物蓄積", but both "bioconcentration" and "biomagnification" are translated as "生物濃縮", though they are different concepts (Weblio, 2012).

There was some confusion as to usage of the term with the same Chinese characters "생물농축 (生物濃縮)" in the Korean and Japanese textbooks. One can see that Korea and Japan have a similar culture by their use of Chinese characters. "濃縮" means an increase of concentration or the concentration of some substances in Korean and Japanese while "蓄積" means accumulation by gathering and collecting (The National Institute of The Korean Language, 2012).

Table 3. Definitions of 생물농축(Bioconcentration) used in Korean textbooks

Textbook	Term	Definition
H-1	생물농축 (Bioconcentration)	Phenomenon in which as substances transfer to higher order consumers through a food chain, they become concentrated and cause serious addiction
H-2	생물농축 (Bioconcentration)	Phenomenon in which a poisonous substance like a pesticide is gradually concentrated through a food chain

H-3	생물농축 (Bioconcentration)	Phenomenon in which heavy metal ions or organic pesticide ingredients become concentrated with a high trophic level
H-4	생물농축 (Bioconcentration)	Phenomenon in which the concentration increases through the process of a food chain
H-5	생물농축 (Bioconcentration)	Phenomenon in which the concentration of a substance entering an organism gradually increases through a food chain
H-6	생물농축 (Bioconcentration)	Phenomenon in which more pollutants are accumulated in organisms at a high trophic level through a food chain
H-7	생물농축 (Bioconcentration)	Phenomenon in which the extent of concentration increases with higher trophic levels through a food chain
H-8	생물농축 (Bioconcentration)	Phenomenon in which substances are continuously transferred to organisms at high trophic level, resulting in a greater extent of concentration
H-9	생물농축 (Bioconcentration)	Phenomenon in which organisms accumulate a chemical in a greater concentration along a food chain

Table 4. Definition of bioaccumulation-related terms used in high school biology textbooks from Japan and U.S.

Textbook	Term	Definition
J-1	生物濃縮	特定の物質が、生物体内に、外部の環境や食物に含まれるよりも高い濃度で蓄積する現象を生物濃縮という (Process in which the concentration of a substance accumulated in the organism exceeds that of ambient environments or diets)
J-2	生物濃縮	特定の物質が外部の環境や食物に含まれる濃度よりも高濃度に蓄積されることがある。また、生態系の食物連鎖を通して物質がつぎつぎに移動し、高次の消費者の体内で高濃度に濃縮される場合がある。このような現象は生物濃縮と呼ばれる (A substance is accumulated in a higher concentration than in ambient environments or diets, and when the substance is more concentrated in high trophic organisms with food chains, it is called 生物濃縮.)
J-3	生物濃縮	特定の物質が生物体内で環境中より高濃度に蓄積されることを生物濃縮という (A substance is accumulated in the organism in a higher concentration than in the environments)
J-4	生物濃縮	ある物質の濃度周囲の環境に比べで生体内でより高くなることを、生物濃縮という (The concentration of a substance is higher in the organism than the ambient environment)
J-5	生物濃縮	生物が、特定の物質をまわりの環境より高い濃度で蓄積する現象を生物濃縮という (Process in which an organism accumulates a substance in a higher concentration than in the ambient environment)

J-6	生物濃縮	特定の物質が、生物体内に、周囲の環境よりも高濃度に蓄積されることがある。この現象は生物濃縮とよばれ (Process in which a substance is accumulated in an organism in a higher concentration than in the ambient environment)
J-7	生物濃縮	特定の物質が、周囲の環境よりも高い濃度で生物体内に蓄積されることを生物濃縮という (Process in which a substance is accumulated in an organism in a higher concentration than in the ambient environment)
A-1	biological magnification	Process whereby substances such as toxic metals and chemicals are passed up the trophic levels of the food web at increasing concentrations
A-2	biological magnification	As these molecules pass up through the trophic levels of the food chain, they become increasingly concentrated.

Types of bioaccumulative substances presented in the textbooks

In the nine high school science textbooks from Korea, a total of 27 kinds of substances, including eight kinds of metallic elements, nine pesticides, and 10 organic compounds, were presented as representative of biomagnified substances (Table 5). Of the substances mentioned, heavy metal, lead, mercury, DDT, and dioxin were mentioned in all the textbooks (Table 6). The Korean textbooks mainly introduced the bioaccumulative phenomenon with so-called heavy metals as exemplified in following excerpts:

> "Although heavy metals exist in small quantities, they are concentrated through a food chain and can do a lot of damage to humans in the long term." H-1 textbook

> "Heavy metals like mercury, lead, and cadmium…are increasingly concentrated through a food chain." H-4 textbook

> "Heavy metals are also concentrated in organisms and cause a lot of damage." H-9 textbook

Table 5. Types of bioaccumulative substances presented in Korean textbooks

Category	Substances	Number
Element	Heavy metal, Mercury, Lead, Cadmium, Chromium, Arsenic, Zinc, Copper	8
Pesticides	Pesticide, Organochlorine pesticide, Insecticide, DDT, Aldrin, Chlordane, Dieldrin, BHC, Defoliant	9
Non-pesticide organic carbon chemicals	Chlorinated hydrocarbons, Dioxine, PCB, Vinyl chloride, Bisphenol-A, Environmental hormones, Endocrine disrupting chemicals, Styrene, Alkyl phenol, Estrogen-like substances	10

Table 6. Presented number of most frequently occurring substances in Korean textbooks

Substance	H-1	H-2	H-3	H-4	H-5	H-6	H-7	H-8	H-9	Number presented
Heavy metal	x	x	x	x	x	x	x	x	x	9
Lead	x	x	x	x	x	x	x	x	x	9
Mercury	x	x	x	x	x	x	x	x	x	9
Cadmium	x	x	x	x	x	x	x	-	x	8
Chromium	x	x	x	-	x	x	-	x	-	6
DDT	x	x	x	x	x	x	x	x	x	9
Dioxine	x	x	x	x	x	x	x	x	x	9
PCB	x	x	x	x	x	x	x	-	x	8
Pesticide	x	x	x	-	-	x	-	x	x	6
Insecticide	x	-	-	x	x	-	-	x	-	4

In contrast, the Japanese high school biology textbooks mostly presented synthetic organic compounds as biomagnified substances (Table 7). The seven high school biology textbooks from Japan mentioned only seven kinds of substances where the concentration becomes higher through the food chain. In the seven Japanese biology textbooks, the most mentioned substance was DDT, followed by PCB and organic mercury. DDT was also presented in the two biology textbooks from U.S. high schools (Table 7). Among the other terms mentioned were organochloric insecticides such as dieldrin, lindane, and chlordane. The biology textbooks from Japan and the U.S. mainly focused on synthetic organic compounds like DDT as examples of biomagnified substances.

Table 7. Types of bioaccumulative substances presented in Japan and U.S. textbooks

Substance	Japan							U.S.	
	J-1	J-2	J-3	J-4	J-5	J-6	J-7	A-1	A-2
DDT	x	x	-	-	x	x	-	x	O
PCB	-	-	x	x	-	-	x	-	-
Organic mercury	-	x	-	-	x	-	x	-	-
Dioxine	-	-	x	-	x	-	-	-	-
Pesticide	-	-	-	-	x	-	-	-	-
Organochlorine chemical	-	x	-	-	-	-	-	-	x
Heavy metal	-	x	-	-	-	-	-	-	-
Dieldrin	-	-	-	-	-	-	-	-	x
Chlordane	-	-	-	-	-	-	-	-	x
Lindane	-	-	-	-	-	-	-	-	x
Toxic metals	-	-	-	-	-	-	-	x	-
Toxic chemicals	-	-	-	-	-	-	-	x	-
No. of presented substances	1	4	2	1	4	1	2	3	5

The Korean textbooks frequently presented examples and explanations about metallic substances. In contrast, the Japanese and American textbooks usually presented synthetic organic compounds as examples of biomagnifying substances. The emphasis on metallic substances in the Korean textbooks may cause Korean students mistakenly to think that all metallic substances are biomagnified and to have misconceptions about essential trace metals. In fact, the only metal that can be regarded as a clear biomagnifying substance is organic mercury (Connell, 1990). The biomagnification of metallic substances is still controversial and needs additional experiments and studies.

When students learn about specific substances or phenomena involved in environmental pollution, they are apt to generalize these specific cases and to apply them to all cases without thinking critically about it (Boyes & Stanisstreet, 1997). Thus, the method of explaining bioaccumulative substances in the high school science textbooks need to be carefully considered. Although the present study did not present quantitative analysis of the examples in the textbooks, most of the Korean textbooks presented notorious incidents of metal pollution such as Itai-itai disease caused by cadmium and Minamata disease caused by mercury to induce students' interest. Metal pollution-related diseases became a matter of

public concern in Japan during the 1960s and 1970s (Kaji, 2012). These diseases seem to result in the public's faith in biomagnification of trace metals.

Properties of bioaccumulative substances presented in the textbooks

All the Korean textbooks analyzed in this study included the notion of low degradability and excretion as properties of bioaccumulative substances (Table 8). Although five textbooks mentioned fat solubility, most of the textbooks explained the properties without distinction according to type. Non-biodegradability and low elimination were also mentioned in most of the textbooks from Japan and the U.S. (Table 9).

The three countries' textbooks were primarily interested in low degradability and elimination of bioaccumulative substances. Interestingly, however, most of them did not include sufficient explanations of fat-solubility, the most important property. Moreover, the bioaccumulative properties of metals and organic compounds have not been distinguished from each other. The presented properties apply to chemical compounds but not to the so-called heavy metals.

The explanation of the properties of bioaccumulative substances seems to be brief and superficial in all the textbooks. The frequently presented properties such as low excretion and degradability are superficial phenomena rather than critical factors. That is, the present explanation in the textbooks could not provide students with scientifically reasonable knowledge to understand the principle of bioaccumulation in organisms. The knowledge of basic chemical principles may be helpful in improving students' understandings of biological issues. When it comes to content that may cover both biology- and chemistry-related characteristics, insufficient explanation of scientific concepts can lead to students' misconceptions (Ko *et al*., 2002). Thus, the inclusion of an explanation about molecular characteristics such as chemical structure in combination with fat-solubility might help students to understand the principles of bioaccumulation beyond rote learning, with critical and integrative thinking.

Table 8. Properties of bioaccumulative substances presented in the textbooks

Textbook	Explanations about properties of bioaccumulative substances in the textbooks
H-1	Chlorinated hydrocarbons do not degrade much so the residual period is long. They can dissolve easily in lipids so are more likely to be concentrated in organisms without excretion. Heavy metals have a property combining with enzymatic proteins so they are easily bioconcentrated without excretion.
H-2	They are mostly accumulated in fatty tissue without degradation and excretion after entering organisms.
H-3	-
H-4	They do not well degrade in organisms' bodies and are not excreted out of the body.
H-5	They do not degrade well in nature or organisms. They are accumulated in organisms and not well excreted. They dissolve more easily in lipids than water, so are accumulated in the fatty tissue of the body.
H-6	The substances do not dissolve well in water and not easily degrade, so if they enter the body of organisms, they combine with lipids and are not well excreted.
H-7	They do not degrade easily and are not excreted in organisms, so they are accumulated in the body.
H-8	If they are absorbed into organisms, they do not degrade well or are not excreted out of the body. So they remain in organisms for a long time.
H-9	They are non-degradable and stable substances in the environment. After entering the body, they do not degrade easily and are not excreted. The most important factor for bioconcentration is water solubility. Water-soluble substances are mostly excreted well out of the body without concentration. Heavy metals are exceptions. Mercury strongly combines with specific tissues of the body which results in concentration despite water solubility. Lipid-soluble substances are easily absorbed in the body and accumulated in fatty tissue. Environmental pollutants like DDT excluding heavy metals are fat-soluble and concentrated in the body.

Table 9. Properties of bioaccumulative substances presented in Japan and U.S. textbooks

	Japan							U.S.	
	J-1	J-2	J-3	J-4	J-5	J-6	J-7	A-1	A-2
Not degraded	O	O	O		O	O		O	
Not excreted	O	O	O	O	O	O		O	
Fat-soluble Accumulated in fatty tissue				O		O			
Residual property						O			

CONCLUSION

It is suggested that high school science/biology textbooks should explain bioaccumulation based on the absorption processes and not focus on biomagnification by food uptake. In addition, explanations about bioaccumulative substances need to distinguish the difference between metallic and chemical substances in order not to create a misconception about essential metals. In order to improve students' understandings of bioaccumulation, the explanations in textbooks need to include more of the critical chemical characteristics of bioaccumulative substances.

We believe that science textbooks in subjects such as biology should provide students with scientifically sound information so that they learn correct basic knowledge for making informed decisions. We also want to suggest that textbooks need to treat bioaccumulation in terms of the recycling of external substances in ecosystems, not just from the perspective of environmental problems. The absorption of substances in organisms from the outside is natural process. The toxicity by bioaccumulation depends on the substance and the organism.

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